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Lake Superior, 1974: PCB, chlorinated insecticides, heavy metals and radioactivity in offshore fish

by

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This is the ninety-ninth Technical Report from the Research and Development Directorate Freshwater Institute Winnipeg, Manitoba

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ABSTRACT

Armstrong, F.A.J., and A. Lutz. 1977. Lake Superior 1974: PCB, chlorinated insecticides, heavy metals and radioactivity in offshore fish. Can. Fish. Mar. Serv. Tech. Rep. 693: vi + 17 p.

Twenty-five samples of lake trout (*Salvelinus namaycush*), siscowet (*Salvelinus namaycush siscowet*), burbot (*Lota lota*), bloater, (*Coregonus hoyi*), lake herring, (*Coregonus artedii*), and slimy sculpin, (*Cottus cognatus*), comprising 1176 fish from 9 locations in Lake Superior in 1974 have been analyzed for contaminants.

Except for one sample of filet, most were of about 50 whole fish; these were grouped in fives to make 10 subsamples which were homogenized for analysis.

PCB, dieldrin, DDT fractions and mercury were determined on all 25 samples, and BHC, methoxychlor, chlordane, As, Cd, Cr, Cu, Pb, Se and Zn on 8. Some samples were also tested for other organics, for other metals and for radioactivity. The methods used are given in outline, with their reproducibility. Mean length, weight and fat content are listed.

PCB was above the present Canadian limit of 2 µg/g in lake trout from 3 locations, DDT is above Canadian and United States limits of 5 µg/g in lake trout from 3 locations, and mercury is at or above the Canadian and United States limits of 0.5 µg/g in lake trout from 6 locations and in burbot from one.

Lake trout and siscowet were markedly higher in PCB, DDT and mercury than the other fishes. Slimy sculpin and lake herring were lowest. There were some small but consistent differences in contamination between locations. Radioactivity was low in the samples analyzed.

RÉSUMÉ

Armstrong, F.A.J., and A. Lutz. 1977. Lake Superior 1974: PCB, chlorinated insecticides, heavy metals and radioactivity in offshore fish. Can. Fish. Mar. Serv. Tech. Rep. 693: vi + 17 p.

En vue d'examiner les agents de contamination, on a analysé en 1974 25 échantillons de touladis (*Salvelinus namaycush*), de siskowets (*Salvelinus namaycush siscowet*), de lottes (*Lota lota*), de ciscos de fumage (*Coregonus hoyi*), de ciscos de lac (*Coregonus artedii*), et de chabots visqueux (*Cottus cognatus*), comprenant 1176 poissons provenant de 9 endroits du Lake Superior.

Mis à part un échantillon de filet, les autres échantillons comprenaient environ 50 poissons entiers; on a groupé ces derniers cinq par cinq pour former 10 sous-échantillons qui furent homogénéisés pour l'analyse.

On a trouvé du PCB, de la dieldrine, des éléments de DDT et du mercure dans les 25 échantillons, ainsi que du BHC, du méthoxychlore, du chlordane, As, Cd, Cr, Cu, Pb, Se et Zn dans 8 échantillons. On a également examiné certains échantillons pour y chercher d'autres substances organiques, d'autres métaux et de la radioactivité. On donne, dans les grandes lignes, les méthodes dont on s'est servi et leur reproductibilité. On énumère la longeueur moyenne, le poids et la teneur en graisse.

Dans des touladis provenant de 3 endroits, le PCB était supérieur à la limite de 2 µg par g actuellement autorisée au Canada; le DDT dépassait les limites du Canada et des Etats-Unis de 5 µg par g dans des touladis provenant de 3 endroits; enfin, dans des touladis de 6 endroits et dans la lotte d'un endroit, le mercure atteignait ou dépassait la limite de 0.5 µg par g autorisée au Canada et aux Etats-Unis.

Les touladis et les siskowets contenaient nettement plus de PCB, de DDT et de mercure que les autres poissons. Les chabots visqueux et ciscos de lac en contenaient le moins. Il existait des différences faibles mais réelles dans le taux de contamination des divers endroits. La radioactivité des échantillons analysés était faible.

INTRODUCTION

The work reported here was commissioned and supported by the International Joint Commission on Boundary Waters. It is a part only of a study by the Upper Lakes Reference Group of the waters of Lake Huron and Lake Superior, being addressed to two of the reference questions posed to the group, namely:

1. Are the waters of Lake Superior and Lake Huron being polluted on either side of the boundary to an extent (a) which is causing or is likely to cause injury to health or property on the other side of the boundary; or (b) which is causing or likely to cause, a degradation of existing levels of water quality in these two lakes or in downstream portions of the Great Lakes System?

2. If the foregoing questions are answered in the affirmative, to what extent, by what causes and in what localities is such pollution taking place?

It will be obvious that chemical analysis of only the offshore fish can give only partial answers to the first question, and that to answer the second requires a great deal of related information from other pollution studies, and knowledge of water and air movements. These have been sought in other investigations and reported in publications of the Upper Lakes Reference Group. Nevertheless, we think it useful to place on record the detailed analyses which we have obtained from adequately large samples, together with outlines of the analytical methods used, and measures of the dispersion of the results. We hope that these provide reliable data for 1974 of a number of possible contaminants and will allow meaningful comparisons in the future.

Fish collections from nine locations in Lake Superior (Fig. 1) were made in the fall of 1974 by Ontario Ministry of Natural Resources and by U.S. Bureau of Sport Fisheries and Wildlife. Lake trout (*Salvelinus namaycush*), siscowet (*Salvelinus namaycush siscowet*), burbot (*Lota lota*), bloater chub (*Coregonus hoyi*), lake herring (*Coregonus artedii*) and slimy sculpin (*Cottus cognatus*) were taken, and the intact fish (except for one sample of lake trout fillets) frozen and shipped to the Freshwater Institute, Winnipeg.

LABORATORY PROCEDURE AND METHODS

Sample composite and homogenization

Samples were received in the frozen state, and were then separated and identified, weighed and measured. Individual weights and lengths were recorded for most specimens, but means only were obtained for some samples of very small slimy sculpins. Fish were grouped, usually by fives, to make 10 composite samples for analysis, size and sex being disregarded. Most of the Canadian samples had already been grouped. In the tables of results the number of fish is denoted by N, the number of

composite samples by n, the grouping being shown, as for example N = 63, n = 10(3x6 + 7x5) indicating that of 10 composite samples there were three groups of 6, and seven of 5 fish.

Large fish were cut up with a bandsaw so as to go into the machine, and then homogenized by at least four passes through a Hobart grinder, by which time the tissue had partly thawed. The resultant mush was put into three separate containers, and refrozen, and kept at -20 C until analyzed. The slimy sculpin samples were homogenized in a blender, by the dry-ice procedure of Benville and Tindle (1970).

Zinc and copper

5 g sample was digested with nitric and sulphuric acids, clearing with 50% hydrogen peroxide as necessary, and heated to fuming. The solution was diluted to 50 ml and zinc determined by AAS at 213.9 nm, in an air-acetylene flame with background correction.

The volume of the remaining solution was noted, the solution neutralized, buffered with acetate to pH 4.75, and copper extracted as its APDC complex into 5 ml MIBK, and determined by AAS at 324.8 nm in an air acetylene flame, with background correction.

Blanks and standards were carried through all operations.

Chromium, lead and cadmium

50 g sample was partially oxidized with nitric acid, dried, ignited in Pyrex glass at 450 C, and the ash treated with nitric acid and re-ignited, repeating until a white ash was obtained. This was dissolved by heating with 2 ml concentrated nitric acid. Occasionally a small residue of sand or gravel remained from which the solution was decanted and washed and made to 50 ml. The residue was rejected. Chromium was determined by AAS at 357.9 nm in an air-acetylene flame, with background correction.

Lead and cadmium were extracted as DDDC complex into 5 ml n-butyl acetate and determined by AAS at 283.3 and 228.0 nm in an air-acetylene flame, using background correction.

Blanks and standards were carried through all stages. The digestion procedures are from Analytical Methods Committee 1967 and 1973. AAS determinations were with Techtron-Varian AA5 and were conventional.

Mercury

0.5 g sample was digested at 70 C with nitric and sulphuric acids, and oxidation completed with permanganate. The solution was cleared with peroxide and made to 25 ml. Mercury was determined by flameless AAS at 253.7 nm. This procedure is that of Armstrong and Uthe (1971). Blanks and standard were carried through all procedures.

Arsenic

1 g sample was digested with sulphuric, nitric and perchloric acids, heated to fumes of SO_3, cooled and diluted to 25 ml. Arsenic was determined by flameless AAS at 193.7 nm by reduction to AsH_3 and decomposition in a heated tube (Vijan and Wood, 1974). An electrodeless discharge lamp was used. Blanks and standard were carried through all operations.

Selenium

1 g sample was digested with perchloric and sulphuric acids, using molybdate as catalyst, heated to fuming, cleared with peroxide, cooled and diluted. Selenium was determined by fluorescence of the 2.3 diaminonaphthalene complex in cyclohexane (Hoffman et al., 1968). A turner model III fluorometer with primary filter #7-60 and secondary 2A-15/58 combination was used.

Extraction for fat and pesticides

4 g sample with 6 g anhydrous sodium sulphate was extracted by shaking with 20 ml hexane-acetone 1:1 for 20 min, in a stainless steel tube and heavy steel ball, and then centrifuged.

Fat

A 5 ml aliquot (representing 1 g tissue) was evaporated in a current of air at room temperature, in an aluminum dish. The residue was weighed and reported as percent fat.

Clean-up

A 5 ml aliquot was taken down to 1 ml in a rotary evaporator and then to dryness under nitrogen, and redissolved in 5 ml hexane. 25 g deactivated Florisil was added and this mixture added to a column containing 25 g Florisil upon a 1 cm layer of anhydrous sodium sulphate. Pesticides and PCB were eluted with 250 ml hexane-methylene chloride (4:1), evaporated to 1 ml and then just to dryness under nitrogen, and redissolved in 5 ml acetone.

This extract was passed through a 7.5 x 0.8 cm column of Fisher Activated charcoal, and organochlorine pesticides eluted with 20 ml acetone-ether (3:1), and the eluate evaporated to dryness under nitrogen and dissolved in 5 ml hexane. This extract was washed 3x with water (previously extracted with hexane) and kept for determination of chlorinated pesticides (Langlois et al., 1964).

PCB's were eluted from the charcoal column with 80 ml benzene, evaporated to dryness and dissolved in 5 ml benzene (Berg et al., 1972).

Chromatography

A Micro-Tek MT 220 was used. Both pesticides and PCB were run on 6 ft column with 2% OV-1 and 4% OV-21 on 80-100 mesh Chromasorb HMDS.

Injection temp 200 C, Column temperature 175 C, detector, tritium foil, 200 C.

All identifications were confirmed on another instrument with 6 ft column having 5% OV-210 on 80-100 mesh Chromasorb HMDS. Injection temperature 230 C Column 190 C, detector ^{63}Ni 260 C.

Spark source mass spectrometry

These analyses were performed by United States Environmental Protection Agency at the Environmental Research Laboratory under the supervision of W.J. Taylor, Analytical Chemistry Branch, who provided the following information.

The preparation deviated from the normal SSMS preparation in that 5 g sample was digested in 50 ml formic acid at 60 C for 6 hours before addition of graphite. An internal spike of yttrium was added to each sample before digestion. After the digestion was completed graphite was added and the samples taken to dryness under IR lamp. The samples were then heated in a muffle furnace at 460 C for 6 hours to destroy all organic residue.

All samples were run in duplicate and the results show little or no difference among the various fish. Results for Zr, Cu, Ni and Al are not reported due to comparable values found in the formic acid blank.

Identification of organic contaminants

These analyses were performed by the U.S. Environmental Protection Agency at the Environmental Research Laboratory-Duluth under the supervision of Gary E. Glass. The results and the outline below of the procedures are from a manuscript submitted to the Upper Lakes Reference Group by Dr. Glass and made available to us.

Preparation

From the frozen homogenized samples, supplied from the Freshwater Institute, Winnipeg, 350 g portions were blended with anhydrous sodium sulphate and extracted with hexane. The solvent was evaporated until the extract was at constant weight. A portion of the extract was dissolved in methylene chloride for gel-permeation clean-up using two 23x200 mm columns of Bio-Rad SX-2 polystyrene beads, methylene chloride as solvent at 4.5 ml/min and a Varian UV detector at 254 nm. Injections of 5 ml were made at 1 h intervals, 100 ml being collected 20 min after injection.

Gas chromatographic analysis

Preparations were concentrated to 2 ml in hexane, and 200 µl transferred to 10 ml hexane for quantitative analysis. From the remainder, 2 µl was used to obtain FID/EC traces before MS analysis. A 2 mm x 2 m OV-101 column programmed from 125 to 225°C at 4°C/min was used.

Mass spectral analysis

Preparations were concentrated to 0.2 ml, 10 µl being injected. The MS system was a Varian MAT CH5 (Kuehl et al., 1974) being scanned from mass 50-500 every 7 sec. It was set at resolution of 1000 and operated at 70 eV.

Radioactivity

For counting approximately 5 g of ash was required. This was prepared from 300 g of fish which was digested with concentrated nitric acid, taken to dryness and incinerated in Pyrex glass at 450 C. The ash was treated with nitric acid and incinerated again, the treatment being repeated until a fairly white residue remained.

Counting was done in the Surveillance Section of Environmental Research WNRE of Atomic Energy of Canada Ltd. at Pinawa, Manitoba, using a Beckman Wide Beta planchet counting system (gas flow) with a method based on low environment work. The count was for either 1000 counts or 1000 minutes. Results for total beta count are expressed as ^{40}K equivalent, and are shown in Table 9. Gamma activity was measured on the whole ash sample, which was pressed to a pellet and counted with a 3"x3" NaI crystal and a Nuclear Data 2400 multichannel analyzer. Results are reported (Table 9) as ^{137}Cs equivalent.

Reproducibility

Replicate analyses gave the results of Table 1. Samples were of fish tissue except for arsenic determination for which the U.S. Bureau of Standards Orchard leaves was used.

RESULTS AND DISCUSSION

Comparability of length and weight, by station

The mean weights of lake trout and siscowet were from 1412 g (Chummy Bank) to 2987 (Apostle Island, for fillet) with lengths of 486 and 613 mm. The ratios, of largest to smallest are 2.1 and 1.3.

Bloater chub ranged from 126 g and 233 mm from Whitefish Point to 217 g and 273 mm at Bateau Rock. The ratios are 1.7 and 1.2. Burbot (3 samples only) are from 425 g and 356 mm (Coppermine Point) to 685 g and 433 mm at Slate Islands. The ratios are 1.6 and 1.2. Slimy sculpins are from 2.4 g and 40 mm at Two Harbors to 4.9 g and 74 mm at Apostle Islands. The ratios, of largest to smallest are 2.0 and 1.8.

Since these values are for the means of groups of 50 fish, it cannot be said that the samples of each species are of uniform size.

Comparability of fat content, by station

Both burbot and slimy sculpin are fairly uniform in fat content, but this is not so for the other fishes. Lake trout and siscowet are

from 15% (Apostle Island whole fish) to 31% (Keweenaw Point). Surprisingly, the Apostle Island fillet sample showed only 9%. For boater chub, values ranged from 9% (Two Harbors) to 16% (Keweenaw Point).

Species differences in contaminant concentrations

Lake trout and siscowet are markedly higher in PCB, DDT and mercury than the other fishes. Slimy sculpin and lake herring are lowest. Whole fish and fillet from Apostle Island can be compared. DDT is markedly lower in fillet, and so are Pb, Cu and Zn. Mercury is higher, PCB substantially the same. These analyses do not seem to be related to the insignificant difference in size, or real difference in fat content of the samples.

Bloater chub and burbot from two positions can be compared. At Coppermine Point there are only small differences in the analyses for contaminants. At Apostle Island, bloater chub has higher DDT (possibly relates to higher fat content, though PCB does not so relate) and lower mercury.

Differences in contamination between locations

Lake trout show least contamination with chlorinated compounds and mercury at Chummy Bank, Whitefish Point and Two Harbors. Keweenaw is notable for high PCB, DDT and mer ury in these fish. Bloater chub at Keweenaw and Apostle Island are slightly more contaminated than at the other stations. Differences in analyses of burbot are small.

Legal requirements

PCB is above the present Canadian limit of 2 µg/g in lake trout from Slate Island, Keweenaw and Coppermine Point. DDT is above U.S. and Canadian limits of 5 µg/g in lake trout from Bateau Rock, Keweenaw and Coppermine Point. Mercury is at or above the U.S. and Canadian limits of 0.5 µg/g in lake trout from Bateau Rock, Slate Island, Keweenaw, Grand Marais, Coppermine Point and Apostle Island, and in burbot from Slate Island.

Radioactivity

Levels of radioactivity are all low, and do not call for comment.

General

Since standard error is in most cases around ±10% of the means, the 95% confidence limits will be near ±20%. The relatively small scatter of results may be ascribable to the sampling procedure in which each analysis is of a composite of about 5 fish.

Qualitative organic analyses (Table 7) are nearly all confirmed by quantitative results where these exist. There is a discrepancy in indications for dieldrin. SSMS results are difficult to relate to analyses by AAS. Zinc values are comparable. Low values for As and Se may be caused by volatilization during ashing. High Co values may be

ly,

due to contamination during grinding. Reasons for other discrepancies are not obvious.

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Table 1. Reproducibility of analyses (µg/g). Mean and SD (±).

	n	Mean	SD (±)
PCB	4	3.93	0.29
Dieldrin	4	0.18	0.05
BHC	4	0.033	0.010
Chlordane	4	0.35	0.11
Total DDT	4	8.66	0.70
op' DDT	4	0.54	0.04
pp' DDT	4	2.35	0.21
op' DDE	4	0.035	0.003
pp' DDE	4	5.31	0.59
pp' DDD	4	0.49	0.03
Arsenic	24	10.6	1.4
	9	14.8	0.52
Cadmium	10	0.055	0.022
Chromium	10	0.06	0.011
Copper	10	0.70	0.05
Lead	10	0.046	0.006
Mercury	20	0.28	0.014
Selenium	10	0.51	0.02
Zinc	10	12.9	0.30

Table 2. LAKE SUPERIOR OFFSHORE FISH. Weight (g), length (mm), fat[1] (%), PCB, pesticide residues and mercury (ug/g). Mean and SE (±).

	Bateau Rock		Slate Islands		Chummy Bank		Whitefish Point		Keweenaw Point		Two Harbors - Duluth		Grand Marais	
	Lake Trout													
N	50		50		50		30		50		41		12	
Weight	1855	80.6	1942	53.0	1412	66.8	2312	193	2071	70.2	2264	73.9	1567	197
Length	532	6.57	538	4.67	486	6.67	565	17.3	546	6.42	586	6.21	512	26.4
n	10 (10x5)		10 (10x5)		10 (10x5)		10 (10x3)		10 (10x5)		10 (1x5+9x4)		10 (2x2+8x1)	
Fat[1]	16	0.78	21	0.61	18	0.67	17	1.11	31	1.13	16	0.78	20	1.84
PCB	1.65	0.14	2.67	0.25	1.15	0.13	0.80	0.07	4.32	0.27	1.85	0.09	1.72	0.22
Dieldrin	0.32	0.03	0.08	0.006	0.06	0.006	0.06	0.003	0.12	0.02	0.08	0.006	0.06	0.008
Total DDT	8.06	0.89	3.99	0.61	1.27	0.15	1.12	0.11	7.08	0.59	1.64	0.14	1.82	0.35
op' DDT	0.53	0.08	0.30	0.03	0.11	0.02	0.12	0.01	0.40	0.03	0.17	0.02	0.14	0.02
pp' DDT	1.93	0.29	1.00	0.19	0.30	0.04	0.25	0.03	1.77	0.15	0.31	0.03	0.42	0.10
op' DDE	0.19	0.02	0.03	0.02	0.10	0.01	0.04	0.004	0.06	0.01	0.03	0.004	0.02	0.003
pp' DDE	4.64	0.44	2.43	0.36	0.68	0.07	0.63	0.07	4.38	0.38	0.97	0.09	1.07	0.20
pp' DDD	0.77	0.14	0.23	0.03	0.08	0.01	0.08	0.007	0.47	0.05	0.16	0.01	0.17	0.03
Mercury	0.50	0.04	0.58	0.04	0.26	0.02	0.27	0.02	0.88	0.03	0.40	0.02	0.52	0.08

[1] Hexane extractable matter

Table 3. LAKE SUPERIOR OFFSHORE FISH. Weight (g), length (mm), fat[1](%), PCB, pesticide residues and mercury (ug/g). Mean and SE (±).

	Bateau Rock		Whitefish Point		Keweenaw Point		Two Harbors - Duluth		Grand Marais	
	Bloater chub									
N	10		64		50		50		50	
Weight	217	31.5	126	3.54	208	4.61	177	6.16	178	4.33
Length	273	11.9	233	2.32	271	2.79	270	2.51	261	2.23
n	2 (2x5)		10 (4x7+6x6)		10 (10x5)		10 (10x5)		10 (10x5)	
Fat[1]	12	0.94	12	0.63	16	0.78	9	0.86	14	0.62
PCB	0.90	0.09	0.63	0.06	1.45	0.09	1.04	0.10	0.87	0.15
Dieldrin	0.06	0.01	0.05	0.002	0.06	0.004	0.04	0.003	0.05	0.004
Total DDT	1.58	0.16	0.87	0.15	1.91	0.14	1.06	0.08	1.14	0.08
op' DDT	0.16	0.02	0.12	0.01	0.18	0.02	0.13	0.009	0.14	0.02
pp' DDT	0.34	0.05	0.25	0.05	0.30	0.02	0.34	0.03	0.26	0.02
op' DDE	0.04	0.01	0.05	0.002	0.02	0.001	0.03	0.004	0.02	0.002
pp' DDE	0.95	0.11	0.19	0.08	1.30	0.12	0.47	0.04	0.63	0.05
pp' DDD	0.09	0.006	0.06	0.006	0.11	0.004	0.09	0.007	0.09	0.05
Mercury	0.21	0.02	0.11	0.01	0.23	0.01	0.14	0.005	0.16	0.004

[1] Hexane extractable matter

Table 4. LAKE SUPERIOR OFFSHORE FISH. Weight (g), length (mm), fat[1] (%), PCB, pesticide residues and mercury (µg/g). Mean and SE (±).

	Slate Islands		Chummy Bank		Whitefish Point		Two Harbors – Duluth		Grand Marais	
	Burbot		Lake herring		Slimy sculpin		Slimy sculpin		Slimy sculpin	
N	35		50		92		50		34	
Weight	685	67.5	586	15.0	4.49	0.20	2.4[2]	-	3.3	0.14
Length	433	12.4	380	3.61	72	0.97	40[2]	-	60[2]	-
n	10 (5x4+5x3)		10 (10x5)		10 (2x10+8x9)		3 (2x17+1x16)		2 (19+15)	
Fat[1]	5	0.35	5	0.82	4	0.22	4	0.33	4	0.5
PCB	1.59	0.24	0.47	0.03	0.16	0.02	0.29	0.05	0.36	0.14
Dieldrin	0.05	0.006	0.01	0.002	0.05	0.003	0.02	0.003	0.02	0.005
Total DDT	1.81	0.34	0.71	0.08	0.16	0.01	0.17	0.01	0.20	0.06
op' DDT	0.09	0.01	0.06	0.007	0.03	0.005	0.02	0.003	0.03	0.01
pp' DDT	0.52	0.09	0.23	0.03	0.04	0.004	0.05	0.009	0.05	0.01
op' DDE	0.01	0.001	0.02	0.004	0.01	0.002	0.01	0.001	0.01	0.00
pp' DDE	1.03	0.23	0.38	0.04	0.06	0.01	0.05	0.003	0.08	0.02
pp' DDD	0.16	0.02	0.02	0.002	0.02	0.003	0.03	0.003	0.04	0.01
Mercury	0.80	0.06	0.16	0.005	0.09	0.006	0.05	0.006	0.16	0.00

[1] Hexane extractable matter

[2] Individual fish not measured

Table 5. LAKE SUPERIOR OFFSHORE FISH Weight (g), length (mm), fat[1] (%), PCB and pesticide residues (µg/g), Mean and SE ±)

	Coppermine Point Div. VII						Apostle Island									
	Siscowet		Burbot		Bloater Chub		Lake Trout		Lake Trout Fillet		Burbot		Bloater Chub		Slimy Sculpin	
N	49		45		49		46		49		50		70		50	
Weight	2488	79.6	425	15.8	175	2.96	2661	136	2987	161	530	21.9	152	4.21	4.87	0.28
Length	522	5.09	356	4.11	252	1.90	594	9.69	613	8.84	415	5.66	236	1.48	74	1.43
n	10	(9x5+1x4)	10	(5x5+5x4)	10	(9x5+1x4)	10	(6x5+4x4)	10	(9x5+1x4)	10	(10x5)	10	(10x7)	10	(10x5)
Fat[1]	26	1.15	6	0.23	14	0.65	15	0.60	9	0.38	4	0.37	12	0.55	5	0.26
PCB	2.27	0.26	1.40	0.11	0.90	0.08	1.80	0.22	1.69	0.15	1.48	0.24	1.44	0.16	0.18	0.02
Dieldrin	0.10	0.01	0.04	0.003	0.06	0.004	0.47	0.04	0.21	0.02	0.06	0.004	0.25	0.04	0.05	0.006
BHC	0.20	0.01	0.04	0.01	0.17	0.01	0.05	0.008	0.03	0.006	0.06	0.008	0.04	0.005	0.01	0.003
Methoxychlor	-[2]		-[2]		-[2]		-[2]		-[2]		-[2]		-[2]		-[2]	
Chlordane	0.59	0.05	0.19	0.008	0.18	0.01	0.54	0.08	0.22	0.02	0.17	0.02	0.24	0.03	0.06	0.006
Total DDT	8.17	0.70	1.16	0.10	1.23	0.08	6.29	0.76	2.99	0.31	1.51	0.24	3.03	0.16	0.18	0.02
op' DDT	0.41	0.04	0.04	0.005	0.13	0.01	0.62	0.07	0.31	0.03	0.06	0.007	0.38	0.03	0.02	0.006
pp' DDT	2.12	0.14	0.32	0.03	0.33	0.03	1.25	0.21	0.67	0.08	0.49	0.07	0.87	0.07	0.06	0.005
op' DDE	0.10	0.01	0.02	0.004	0.07	0.01	0.34	0.04	0.14	0.01	0.03	0.006	0.14	0.02	0.01	0.002
pp' DDE	5.15	0.49	0.68	0.07	0.60	0.06	3.28	0.48	1.50	0.20	0.75	0.16	1.38	0.08	0.07	0.007
pp' DDE	0.39	0.04	0.10	0.01	0.10	0.004	0.80	0.05	0.37	0.03	0.18	0.02	0.26	0.05	0.02	0.003

[1] Hexane extractable matter [2] Less than 0.05

Table 6. LAKE SUPERIOR OFFSHORE FISH Metals (ug/g), Mean and SE (±) For weight, etc. see Table 2.

	Coppermine Point Div. VII						Apostle Island									
	Siscowet		Burbot		Bloater Chub		Lake Trout		Lake Trout Fillet		Burbot		Bloater Chub		Slimy sculpin	
n	10		10		10		10		10		10		10		10	
Arsenic	0.61	0.02	0.54	0.03	0.70	0.03	0.41	0.02	0.33	0.02	0.71	0.04	0.74	0.04	0.24	0.007
Cadmium	0.018	0.001	0.032	0.002	0.030	0.006	0.011	0.001	0.002	-[1]	0.030	0.002	0.055	0.004	-[2]	
Chromium	0.04	0.004	0.07	0.004	0.08	0.002	0.05	0.005	0.07	0.002	0.06	0.003	0.05	0.001	-[2]	
Copper	0.90	0.05	1.61	0.02	0.70	0.02	0.75	0.04	0.46	0.02	1.52	0.06	0.70	0.03	4.59[3]	0.22
Lead	0.025	0.003	0.046	0.002	0.066	0.004	0.050	0.005	0.012	0.002	0.038	0.004	0.046	0.003	-[2]	
Mercury	0.78	0.03	0.40	0.02	0.20	0.01	0.39	0.02	0.51	0.04	0.48	0.07	0.09	0.005	0.07	0.004
Selenium	0.54	0.02	0.65	0.01	0.62	0.02	0.40	0.02	0.41	0.01	0.51	0.01	0.42	0.004	0.60	0.01
Zinc	11.4	0.40	12.9	0.23	19.1	0.47	12.9	0.31	3.61	0.09	13.9	0.20	18.3	0.66	21.0[3]	0.36

[1] Less than 0.001 [2] Not determined [3] N = 8

Table 7. LAKE SUPERIOR OFFSHORE FISH. Detected (+) and not detected (-) organic compounds in lake trout.

	Coppermine Point	Apostle Island
Biphenyl	-	-
Naphthalene and methyl naphthalenes	+	+
Phenanthrene and methyl phenanthrenes	+	+
Diethyl Phthalate	+	+
Dibutyl phthalate	+	+
Di-2-ethyl hexylphthalate	+	+
Trichlorobenzene	+	-
Tetrachlorobenzene	+	-
Pentachlorobenzene	+	-
Hexachlorobenzene	+	+
Octachlorobiphenyl (3 isomers)	+	+
Octachlorostyrene	-	-
1,2,3,4,5,6, Hexachloro cyclohexane (alpha)	-	+
" (gamma)	+	-
Heptachlorepoxide	+	+
Chlordane (cis-and trans-_	+	+
Nonachlor (cis- and trans-)	+	+
Oxychlordane	+	-
Dieldrin	+	-
pp' DDT	+	+
op' DDE	+	+
pp' DDE	+	+
pp' DDD	+	+
pp' DDMU	+	+
Toxaphene components ($C_{10}H_8Cl_{7.8}$, trans-_	+	+
Methyl benzothiophene	-	-

Table 8. LAKE SUPERIOR OFFSHORE FISH. Analysis by spark source mass spectrometry (μg).

	Coppermine Point	Apostle Island
	Lake Trout	
Pb	0.10	0.11
Nd	-	0.035
Pr	-	-
Ce	-	0.005
La	-	0.13
Ba	0.055	0.12
Cs	0.010	0.020
I	16	25
Te	-	0.010
Sn	7	0.43
In	0.030	0.13
Cd	-	-
Ag	0.045	0.18
Rh	-	0.020
Mo	0.025	0.22
Sr	1.2	2.3
Rb	2.8	3.8
Br	3.1	3.2
Se	0.18	0.20
As	0.002	0.005
Ge	0.24	0.27
Ga	0.015	0.005
Zn	21	27
Co	0.36	0.37
Fe	14	12
Mn	2.7	3.7
Cr	1.6	0.98
V	0.085	0.085
Ti	0.16	0.20
Sc	0.055	0.12
F	0.020	0.46

Zr, Cu, Ni and Al present in formic acid

Table 9. LAKE SUPERIOR OFFSHORE FISH. Radioactivity. Total beta activity as ^{40}K equivalent (pCi/g wet weight)
Gamma activity as ^{137}Cs (pCi/g wet weight) Mean and S.E. (±)

	Bateau-Rock Lake Trout		Keweenaw Point Lake Trout		Coppermine Point Lake Trout		Apostle Islands Lake Trout		Lake Trout fillet	
N	50		50		49		46		49	
n	10		10		10		10		10	
Total beta	2.04	0.06	1.68	0.04	1.87	0.06	2.21	0.08	2.97	0.09
Gamma	0.443[1]	0.037[1]	0.390	0.042	0.416	0.018	0.431	0.025	0.670	0.038

[1] n=9

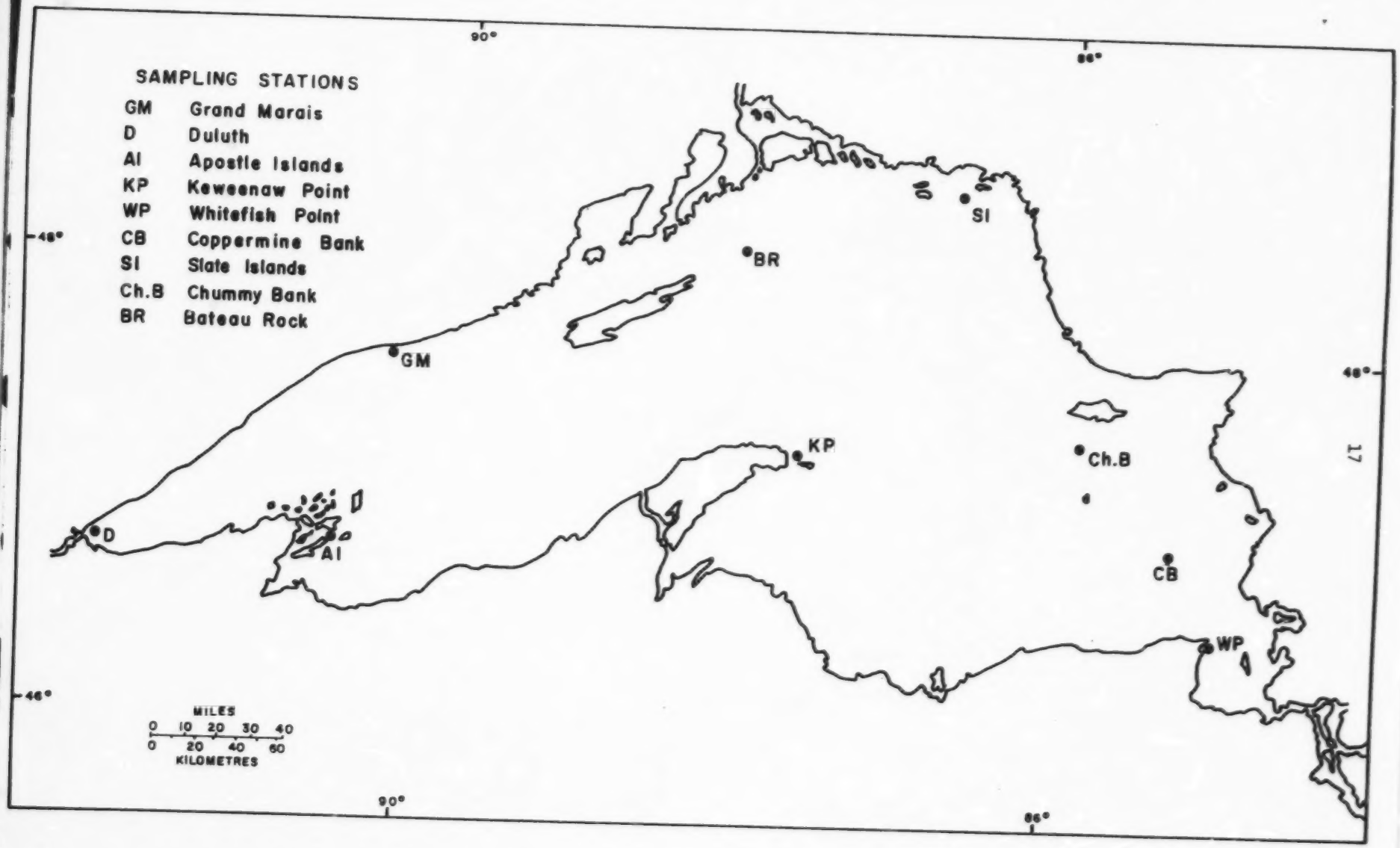

Fig. 1. Lake Superior and sampling locations

POOR

QUALITY

ORIGINAL